

# Power Corrections and CP Phases

Tsung-Wen Yeh

*Department of Nature Science Education, National Taichung University, Taichung 403, Taiwan*

**Abstract.** I investigate the impact of power corrections from possible known sources on the understanding of CP violation phenomenology from  $B$  decay processes. By comparing the theoretical predictions with experimental data, it is possible to pindown the uncertainty related to power corrections. This may help to search for new physics beyond the standard model. In the heavy quark mass limit, there exist perturbation theories for describing rare hadronic  $B$  decays from first principle of QCD. However, the leading order theoretical predictions may not be able to explain the experimental branching ratios and CP asymmetries in a consistent way. It was also found that the power suppressed corrections are important for understanding of some measured processes. The existence of power corrections is then one major uncertainty of perturbation theories. The search for new physics beyond the standard model is also one main activity in studies of rare hadronic  $B$  decays. One large uncertainty is due to hadronic effects. Thus, more controls over the hadronic effects can significantly improve the search for new physics.

**Keywords:** B physics, factorization, power corrections

**PACS:** 12.38.Bx, 14.40.-n

## INTRODUCTION

New averaged experimental data  $10^6 \times Br(B^- \rightarrow \pi^- \bar{K}^0) = 24.1 \pm 1.3$ ,  $10^6 \times Br(\bar{B}^0 \rightarrow \pi^0 \bar{K}^0) = 11.5 \pm 1.0$ , and  $10^6 \times Br(\bar{B}^0 \rightarrow \pi^0 \pi^0) = 1.45 \pm 0.29$  [1] are larger than the corresponding leading twist QCDF predictions  $10^6 \times Br(B^- \rightarrow \pi^- \bar{K}^0)_{QCDF} = 20.3$  and  $10^6 \times Br(\bar{B}^0 \rightarrow \pi^0 \bar{K}^0)_{QCDF} = 8.0$ ,  $10^6 \times Br(\bar{B}^0 \rightarrow \pi^0 \pi^0)_{QCDF} = 0.7$  [2]. This seems an amazing puzzle, since the other QCDF predictions except of these three modes are consistent with experiments. Many resolution mechanisms to this puzzle have been proposed. For example, the large charm penguin coefficient, next-to-leading order radiative corrections, or, new physics models. The common uncertainties related to these different approaches are related to the determination of the hadronic matrix elements. Without going beyond the standard model and introducing more model uncertainties, it is, therefore, interesting to seek solutions within QCDF. Since the relevant leading contributions are related to the penguin operators, the penguin loop radiative corrections and chirally enhanced power suppressed corrections can get involved. There also exist unexplored power suppressed corrections related to penguin operators to have the same order of magnitude as the leading ones. It is then possible to find out some resolutions within QCDF.

In this work, I would like to show that the required contributions may come from the twist-3 power suppressed corrections related to the three parton Fock state of the emitted final state mesons. Before going to the details of calculations, let's first see the final result. The predictions with three parton corrections are  $10^6 \times Br(B^- \rightarrow \pi^- \bar{K}^0)_{QCDF+G3} = 23.5$ ,  $10^6 \times Br(\bar{B}^0 \rightarrow \pi^0 \bar{K}^0)_{QCDF} = 9.7$ , and  $10^6 \times Br(\bar{B}^0 \rightarrow \pi^0 \pi^0)_{QCDF} = 1.1$ . It is

noted that the corrected predictions are more closer to the central values of the data than the uncorrected, although the prediction for the  $\bar{B}^0 \rightarrow \pi^0 \bar{K}^0$  mode is still lower than. The differences between the corrected predictions and the data are reduced to only 10%, which is within the experimental errors. Therefore, the more precise measurements and more accurate theories can further improve the consistency. In the rest part of the text, I will first give a brief introduction to the employed collinear expansion for calculating the twist-3 power corrections from the three parton  $q\bar{q}g$  Fock state of the emitted final state mesons. The collinear expansion method was then applied to calculate the tree and one loop radiative corrections. In the last part, the numerical results and a short conclusion about this work will be given.

## COLLINEAR EXPANSION

The basics of the employed collinear expansion method was established for deep inelastic scattering processes and Drell-Yan processes. Lately, the expansion method was generalized to exclusive hard processes. Using this expansion method, it is straightforward to derive the relevant expanded amplitudes. After some manipulations, the relevant amplitudes can always be expressed in terms of one convolution integration over the loop parton momenta  $l_{q_1}$  and  $l_g$

$$\int \frac{d^4 l_{q_1}}{(2\pi)^4} \int \frac{d^4 l_g}{(2\pi)^4} \text{Tr}[H_v(l_{q_1}, l_g) \phi^v(l_{q_1}, l_g)], \quad (1)$$

where  $H_v(l_{q_1}, l_g)$  represents the partonic amplitude for the relevant diagrams, and  $\phi^v(l_{q_1}, l_g)$  denotes the amplitude with which the  $q\bar{q}g$  state composes of the meson  $M_2$

$$\phi^v(l_{q_1}, l_g) = \int d^4 x \int d^4 y e^{il_{q_1} \cdot x} e^{il_g \cdot y} \langle M_2 | \bar{q}_1(x) (-g A^v(y)) q_2(0) | 0 \rangle. \quad (2)$$

The trace is taken over fermion and color indices. By making a scale analysis for the loop momenta  $l_{q_1}$  and  $l_g$  in  $H_v(l_{q_1}, l_g)$ , it is not difficult to find that the dominant contributions should come from the regions in which both  $l_{q_1}$  and  $l_g$  are collinear to the momentum  $q$  of the emitted meson, and the other possible regions are power suppressed by at least one additional order of  $1/m_b$ . It is followed by making a Taylor expansion for  $H_v(l_{q_1}, l_g)$  with respect to  $\hat{l}_{q_1} = \alpha_{q_1} q$  and  $\hat{l}_g = \alpha_g q$  as

$$H_v(l_{q_1}, l_g) = H_v(\hat{l}_{q_1}, \hat{l}_g) + H_{\mu\nu}(\hat{k})(k - \hat{k})^\mu + \dots, \quad (3)$$

where  $H_{\mu\nu}(\hat{k}) = \partial H_v(\hat{k}) / \partial k^\mu$  and  $k = l_{q_1} + l_g$ . The  $(k - \hat{k})^\mu$  factor is absorbed by  $\phi^v(l_{q_1}, l_g)$  to introduce the field strength  $G^{\mu\nu}(y)$  in the matrix element  $\langle M_2 | \bar{q}_1(x) \sigma^{\alpha\beta} \gamma_5 g G^{\mu\nu}(y) q_2(0) | 0 \rangle$ . In covariant gauge, the longitudinal component  $n \cdot A q^\nu$  of the gluon field  $A^\nu$  is dominant with  $n \cdot q = 1$ . The contraction of  $H_v$  with  $q^\nu$  vanishes due to the Ward identity.  $H_{\mu\nu}(\hat{k})$  can be decomposed as  $H_{\mu\nu}(\hat{k}) = A(\hat{k}) g_{\mu\nu} + B(\hat{k}) \sigma_{\mu\nu}$ . The  $g_{\mu\nu}$  term as contracted with  $\phi^v(k)$  is reduced to a gauge phase factor of the corresponding two parton function. The contraction of the  $\sigma_{\mu\nu}$  term with  $(k - \hat{k})^\mu \phi^v(k)$  leads to the result. After explicit calculations, the three parton contributions are free from end point divergences.

## NUMERICAL ANALYSIS

I now apply the calculations to make predictions and to compare them with the data. The factorization scale of the coefficient functions is chosen to be  $m_b$ . The input parameters are referred to [2]. The decay amplitudes are expressed in terms of Wilson coefficients, vertex, penguin and hard spectator corrections, annihilation corrections, and factorized amplitudes.

In Table 1, the predicted CP-averaged branching ratios and direct CP asymmetries for  $B \rightarrow \pi K$  and  $B \rightarrow \pi\pi$  decays and the experimental data collected by HFAG group [1] are shown. The three parton contributions play an important role in understanding of  $B \rightarrow \pi K$  decays. For tree dominant  $B \rightarrow \pi\pi$  processes, twist-3 three parton contributions have small effects as expected. Due to large uncertainties in direct CP asymmetry measurements for  $B \rightarrow \pi K, \pi\pi$  decays, it is still difficult to reach a solid conclusion. It is noted that the predicted  $A_{CP}(B^- \rightarrow \pi^- K^0)$  and  $A_{CP}(\bar{B}^0 \rightarrow \pi^0 \bar{K}^0)$  have the same sign with the data. Since the predicted branching ratios are close to the data, while the predicted direct CP asymmetries deviate from the data a lot, this analysis results in one restricted possibility for new physics which should contribute in different signs but would have almost equal magnitudes for particle and antiparticle decay modes.

**TABLE 1.** The branching ratios are in units of  $10^{-6}$  and the CP asymmetries in units of  $10^{-2}$ .

Br	QCDF	expt	$A_{CP}$	QCDF	expt
$B^- \rightarrow \pi^- \bar{K}^0$	23.5	$24.1 \pm 1.3$	$B^- \rightarrow \pi^- \bar{K}^0$	-0.7	$-2.0 \pm 3.4$
$B^- \rightarrow \pi^0 K^-$	12.3	$12.1 \pm 0.8$	$B^- \rightarrow \pi^0 K^-$	8.7	$4 \pm 4$
$\bar{B}^0 \rightarrow \pi^+ K^-$	20.2	$18.2 \pm 0.8$	$\bar{B}^0 \rightarrow \pi^+ K^-$	5.9	$-10.9 \pm 1.9$
$\bar{B}^0 \rightarrow \pi^0 \bar{K}^0$	9.7	$11.5 \pm 1.0$	$\bar{B}^0 \rightarrow \pi^0 \bar{K}^0$	4.6	$9 \pm 14$
$\bar{B}^0 \rightarrow \pi^+ \pi^-$	7.9	$4.5 \pm 0.4$	$\bar{B}^0 \rightarrow \pi^+ \pi^-$	-10.1	$-37 \pm 10$
$B^- \rightarrow \pi^- \pi^0$	5.9	$5.5 \pm 0.6$	$B^- \rightarrow \pi^- \pi^0$	0.01	$-2 \pm 7$
$\bar{B}^0 \rightarrow \pi^0 \pi^0$	1.1	$1.45 \pm 0.29$	$\bar{B}^0 \rightarrow \pi^0 \pi^0$	60.6	$28^{+40}_{-39}$

## ACKNOWLEDGMENTS

The author appreciates partial financial support from the National Science Council under grand numbers NSC-93-2112-M-142-001 and NSC-94-2112-M-142-001 .

## REFERENCES

1. H. F. A. Group, arXiv:hep-ex/0505100.
2. M. Beneke and M. Neubert, Nucl. Phys. B **675**, 333 (2003) [arXiv:hep-ph/0308039].